FIELD, LAB AND MODELLING STUDY OF MICROSCALE COPEPOD DISTRIBUTIONS

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LONG TERM GOALS

The long term goal of the present work is to determine the microscale (cm's-m's) vertical distribution of herbivorous copepods relative to environmental characteristics, such as food concentration, by understanding their reactions to the environment. Specifically, we are interested in the foraging strategies that copepods might use to navigate through prey patches, as these strategies should, in part, determine the copepods' vertical distribution. Understanding the microscale distribution of copepods relative to their food will allow more realistic predictions of the grazing impact of herbivorous zooplankton on their phytoplankton food source, and better estimates of daily copepod growth.

OBJECTIVES

The current objectives of the research are to quantify changes in ingestion and swimming behavior over short (<2 hour) time scales, under a suite of different food and acclimation conditions. These data will be used to drive individual-based, spatially resolved foraging models forced with field observations of the phytoplankton distributions. These models will examine both the impact of copepod grazing on *in situ* phytoplankton patchiness, and the impact of phytoplankton patchiness on the microscale distribution of the copepods. As part of this study, new techniques to determine the gut content of individual copepods are being developed, in order to couple individual behavior to individual feeding success.

APPROACH

Acartia clausi, one of the dominant coastal calanoid copepods in temperate waters, was chosen as the organism for study. It is a major food source for larval fish, it eats diatoms and dinoflagellates, and has only minimal effects of previous feeding history on current feeding, making it an excellent animal for laboratory manipulation. The animals are caught locally and then conditioned under different feeding and temperature regimes before being placed in the experimental aquaria for the video experiments. Within the aquaria, small vertical patches of phytoplankton can be created by slow layering with waters of slightly different densities and phytoplankton concentrations. The animals are

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then videotaped at high magnification for up to two hours as they feed and swim within the small aquaria. During the course of the video experiment, copepods are taken every ten minutes from replicate vessels and then frozen in liquid nitrogen for subsequent measurements of gut fluorescence. The video is then digitized into a computer so that the swimming motions of the copepods (swimming speed, direction, types of swimming behaviors, etc.) can be compared to length of time in the experimental chamber, acclimation regime, and gut content. Once these relationships are known, they can be used to parameterize 1 and 2D individual based simulation models of copepods swimming through theoretical and field measured distributions of food. The 2D model can use the fluorescence data collected from the OSST device (developed under the parent ONR grant) as the food distribution, assuming fluorescence to be a good indicator of amount of available food.

To examine natural gut content levels and individual variability in gut contents, copepods have been collected regularly from the field. Upon collection, the copepods are immediately placed in liquid nitrogen for transport back to the lab where the gut content can be fluorometrically analyzed. Samples are taken from multiple depths from the water column. *In situ* temperature, salinity, and fluorescence are measured at the sample site using a CTD equipped with a fluorometer. Using a vertical 1D simulation model forced by the data from the CTD/fluorometer, and parameterized with laboratory data on swimming behavior and ingestion versus food concentration and acclimation history, predictions of the average gut content/copepod can be estimated for the field caught animals. Deviations from the predicted values should increase understanding of the processes controlling feeding and behavior *in situ*.

WORK COMPLETED

Eight video experiments of copepod swimming behavior, with four including a gut fluorescence component, have been conducted so far. In addition, four experiments looking at gut contents alone, without video, have been conducted. Pre-experimental feeding acclimation has ranged from starvation for 24 hours before the experiment, to fully saturating food levels for 24 hours. Experiments have also been run before dusk, at dusk, and after dusk, in order to examine any effects that endogenous rhythms or light levels may have on the swimming and feeding behavior of the copepods. The digitized data from 2 of the experiments have been analyzed for swimming behavior, and the gut fluorescence from 3 of the experiments have analyzed. The bulk of the gut fluorescence analysis will continue after the technique for analyzing individual gut fluorescence is fully developed.

The 2D individual-based simulation model of copepods foraging through a patchy food environment is complete, and has been used to assess strategies that copepods might use when foraging in various idealized food distributions. It is now ready for parameterization with laboratory derived values from the video experiments. The model is partially based on the 1D model which was completed in the earlier phases of this research.

Field collections of copepods were made once a week over a six week period. Samples were taken from two depths (above and below the seasonal thermocline), and from three stations on each date. Gut fluorescence of the target species was determined for 3 of the sample dates, and compared with predictions of gut fluorescence based on a simple analytical model forced by data from CTD/Fluorometer measurements taken at each sample site. Additionally, samples of copepods were taken from multiple depths during an August cruise to the Saanich Inlet, British Columbia, Canada, with concurrent measurements using the OSST/FishTV.

RESULTS

Early results from experiments examining behavior versus time since the addition of a pulse of food to the experimental aquaria have shown an increase in the time spent "jumping" as time increases, versus a control tank where no additional food was added (Fig. 1). More analysis is needed, however, to confirm that this trend is statistically significant. Because the three behaviors which these copepods exhibit (a slow cruise-type swimming, a rapid upward jump, and no movement or sinking) are mutually exclusive, a decrease in the time spent sinking was found to complement the increase in time spent jumping for the copepods in the treatment group of this experiment.

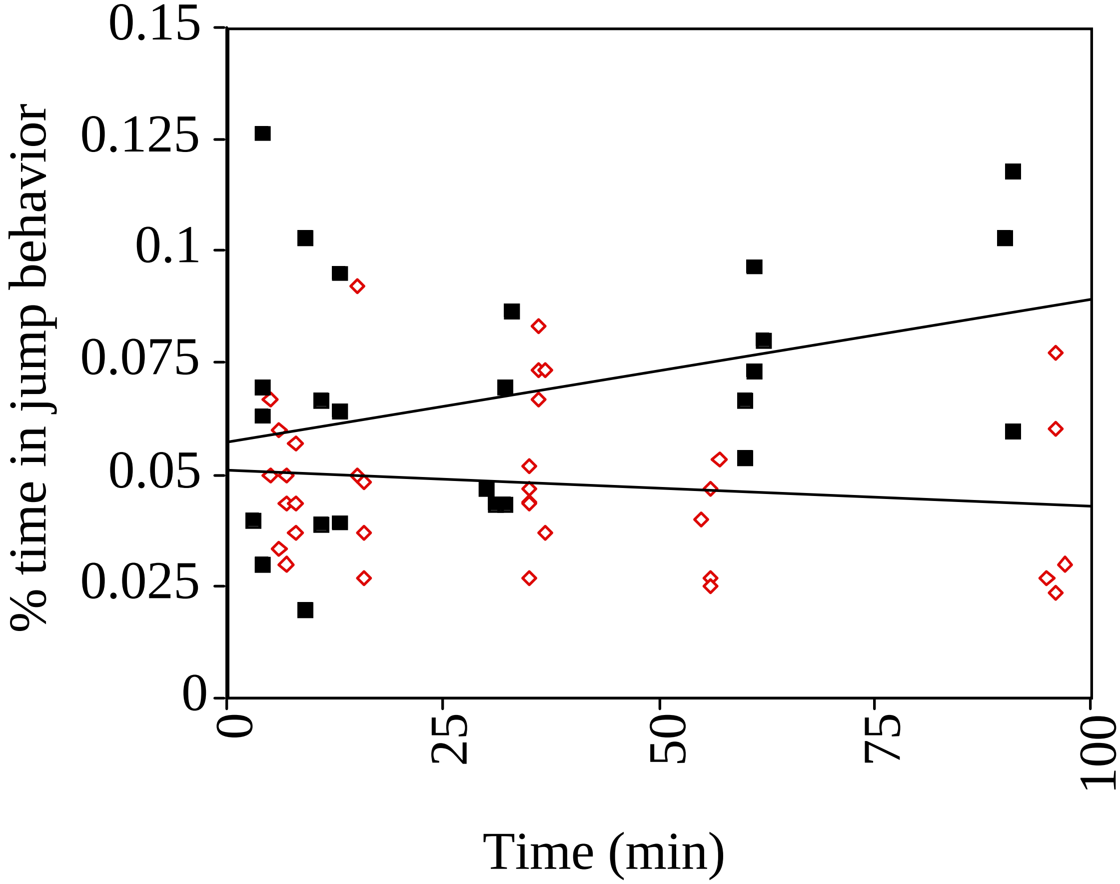

Figure 1. % time spent in jump behavior versus time since a pulse of food was added to the experimental tank (squares), versus a control chamber where no food was added (diamonds).

Gut contents (as derived from gut fluorescence) were found to increase to a maximum value within 30 minutes for animals which had been starved for 24 hours and then fed a pulse of food at the beginning of an experiment as in the video experiment discussed above(Fig. 2).

From the three analyzed field collections, 2 of the days showed no difference in the gut fluorescence between animals collected at the surface and animals collected below the thermocline and within the subsurface chlorophyll maximum (a vertical separation of 10 meters). On one sample date, however, there was a trend toward higher gut fluorescence in surface samples than deeper samples, even though our analytical model would have predicted the opposite due to the colder temperatures and higher food availability at depth.

The field data showing a gut-content difference in animals separated by only 10 meters vertically indicate that these animals must be mixing over time scales longer than 60 minutes, which is the time it takes to fill and then empty their guts. More rapid exchange would lead to a more homogeneous vertical distribution of gut fullness. The swimming and sinking speeds of these animals would allow them to cover the distance of 10 meters in less than a few minutes, indicating that they must be maintaining their vertical position behaviorally.

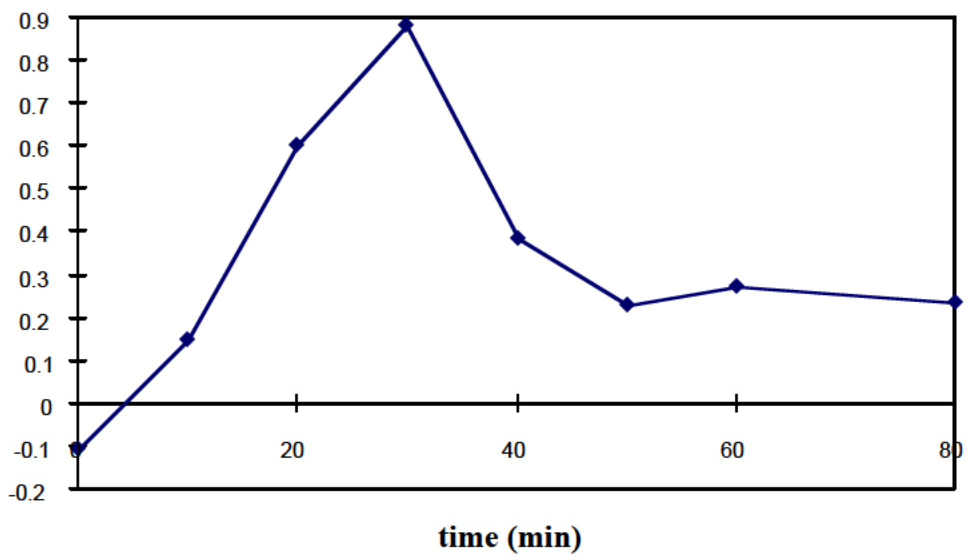

Figure 2. Relative gut fluorescence per copepod versus time.

Through our theoretical 1 and 2D modeling work, we see evidence that a successful strategy for foraging in patch structures similar to those we have measured in the field requires the copepod to respond quickly to the presence of a patch in both feeding and swimming behavior (within minutes) in order to stay within the patch. This appears to be consistent with our laboratory data.

IMPACT

These findings are a significant first step towards quantifying how a herbivorous copepod forages within its patchy food environment. The combination of laboratory, field and modelling experiments is allowing us to rigorously test hypotheses relevant to the spatial dynamics of herbivorous copepods and other small acoustic targets in the ocean.

TRANSITIONS

RELATED PROJECTS

This work is closely allied with the parent project (Jaffe and Franks) in utilizing the unique acoustic and optical data afforded by the FishTV and OSST to calibrate, force and test the models and laboratory experiments.